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The late Barremian *Halimedides* horizon of the Dolomites (Southern Alps, Italy)

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ABSTRACT

A new trace fossil marker level, the *Halimedides* horizon, is proposed for the Lower Cretaceous pelagic to hemipelagic succession of the Puez area (Southern Alps, Italy). The horizon occurs in the middle part of the late Barremian *Gerhardtia sartousiana* Zone (*Gerhardtia sartousiana* Subzone). It is approximately 20 cm thick and restricted to the uppermost part of the Puez Limestone Member (marly limestones; Hauterivian–Barremian; Puez Formation). It is fixed to the top 20 cm of bed P1/204. The grey–whitish limestone bed of the *G. sartousiana* Zone is penetrated by Aptian red marls–siltstones of the Redbed Member. The horizon is documented for the first time from the Southern Alps, including the Dolomites, and can be correlated with other Mediterranean localities. The trace fossil assemblage of this marker bed with the co-occurrence of *Halimedides*, *Spongeliomorpha* and *Zoophycos* sheds light on the Lower Cretaceous sedimentological history and current system of the Puez area within the Dolomites. It also highlights the palaeoenvironmental evolution of basins and plateaus and provides insights into the late Barremian interval.

1. Introduction

Lower Cretaceous pelagic to hemipelagic sediments cover relatively small, restricted areas in the higher Dolomites (Southern Alps). In the Southern Alps, cephalopod-bearing deposits are mainly recorded in two different facies (Lukeneder, 2010): the calcareous limestones of the Biancone Formation (= Maiolica Formation in the Appenines and basinal settings of the Southern Alps; see Weissert, 1981) and the more marly Puez Formation (Lukeneder, 2010). During the late 19th and early 20th centuries, a rich fauna of cephalopods was collected from Lower Cretaceous sediments of this area by Haug (1887, 1889) and Uhlig (1887). The most recent contributions on the Lower Cretaceous of the Puez area were published during the last decade and focused on stratigraphy (Lukeneder and Aspmair, 2006), palaeoecology (Lukeneder, 2008) and lithostratigraphy (Lukeneder, 2010, 2011).

The biostratigraphy of the Lower Cretaceous Puez area is based on microfossils (e.g., forminifera), nannofossils and ammonites (Lukeneder and Aspmair, 2006; Lukeneder, 2010, 2011, in press). A detailed ammonite biostratigraphy and zonation was still missing because ammonites have not been collected bed-by-bed over the last 150 years. Lukeneder (in press) presents the results of the systematic ammonite sampling at the Puez section and concludes with a detailed ammonite zonation of that locality.

A unique sedimentologic feature occurs in the middle part of the Puez Formation (Lukeneder, 2010). At the top of the Puez Limestone Member a trace fossil level including numerous *Halimedides* is observable in the whole of the Puez area. The horizon is preliminarily dated on the basis of ammonites as late Barremian from the *Gerhardtia sartousiana* Zone (*Gerhardtia sartousiana* Subzone; Lukeneder, in press). The trace fossil horizon is restricted to the uppermost part of log P1, bed P1/204. The latter bed is penetrated by trace fossils and filled with red sediment from the overlying Puez Redbed Member of Aptian age. The *Halimedides* horizon is described for the first time from this area and can be compared with other Cretaceous alpine localities where this trace has been studied (Gaillard and Olivero, 2009).

2. Geological setting and section studied

2.1. Location

The outcrops are situated on the Puez-Odle-Gardenaccia Plateau in the Dolomites (maps Trentino–Alto Adige; South Tyrol; Lukeneder,

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2010). The exact position of the main outcrop is about 30 km north-east of Bolzano (Fig. 1A; E 011°49′15″, N 46°35′30″; Lukeneder, 2010). The grey-, green- to red-coloured sedimentary succession of the Puez Formation is located on the southern side of the Piz de Puez. It can be best studied in ravines called P1, P2 and P3 (Lukeneder, 2010).

2.2. Geological setting and palaeogeography

The studied sites are outcrops on the Puez-Gardenaccia Plateau (Lukeneder, 2010). They are located within the area of the Puez-Odle-Geisler Natural Park in the northern part of the Dolomites. The Dolomites (Permian–Cretaceous) are an internal part of the Southern Alps; they are a northern Italian mountain chain that emerged in the aftermath of the deformation of the passive continental margin of the Adriatic (= Apulian Plate) of the South Alpine-Apennine Block (Dercourt et al., 1993; Fourcade et al., 1993; Bosellini, 1998; Cecca, 1998; Stampfli and Mosar, 1999; Scotese, 2001; Stampfli et al., 2002; Bosellini et al., 2003). This block was limited by the Penninic Ocean (= Alpine Tethys) to the north and the Vardar Ocean to the south-east (Scotese, 2001; Stampfli et al., 2002). The Puez Formation includes three members from bottom to top: Puez Limestone, Puez Redbed and Puez Marl (Lukeneder, 2010). The succession shows a transition from limestones and marly limestones into a marl-marly limestone alternation in the upper half of the section. A detailed description on the geology and lithostratigraphy is given in Lukeneder (2010). The complex Mediterranean palaeogeography and the presence of microplates in the Tethyan oceanic corridor between Africa and Europe was discussed in detail by Lukeneder (2010, 2011). The Trento Plateau extends from the south (around Trento) up to the Puez region and was formerly surrounded by two basins: the Lombardia Basin to the west and the Belluno Trough to the east (Lukeneder, 2010). According to recent investigations by Muttoni et al. (2005), the Lombardia Basin (see Fig. 1 for geographic names) and thus the adjacent Trento Plateau to the east were located at approximately 20°N in Valanginian–Hauterivian times and at almost 30°N in the Aptian.

The main investigation area around Puez is compared herein with the well-known outcrop of the Breggia Gorge (Figs. 1, 2) in Balerna, southern Switzerland (Gandolfi, 1942; Rieber, 1977; Weissert, 1979, 1981; Weissert et al., 1979; Arthur and Premoli-Silva, 1982; Gaillard and Olivero, 2009; Föllmi et al., 2011). The Puez Formation (Lukeneder, 2010) at Puez is comparable to the Maiolica Formation of the Breggia Gorge section (E 009°42′43″, N 45°51′20″). Arthur and Premoli-Silva (1982) first dated a biostratigraphical gap at Balerna of late Barremian–early late Aptian

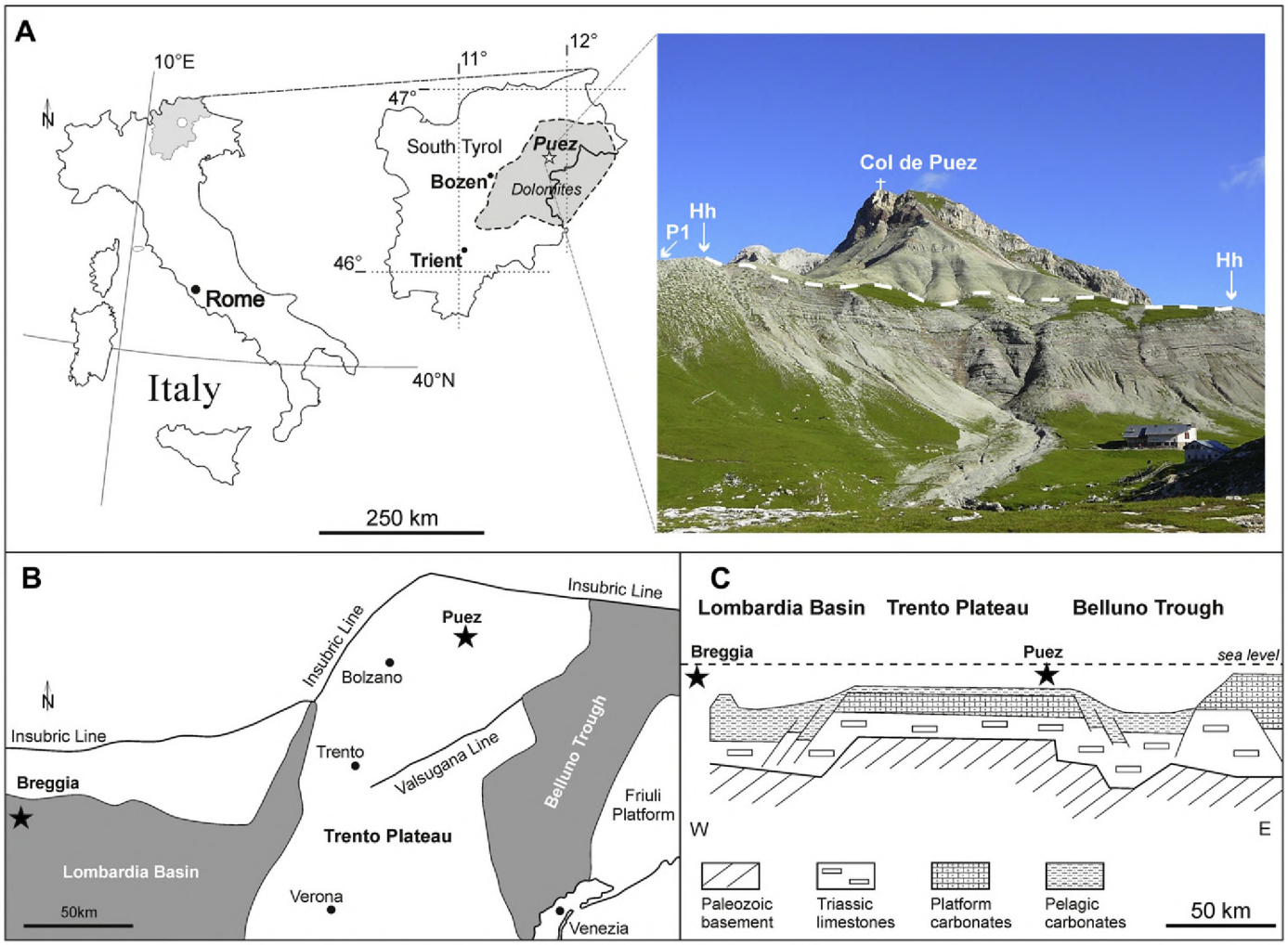


Fig. 1. Locality map of the Lower Cretaceous Puez area. A, Puez area (white star) and indicated outcrop position (P1) within the Dolomites, South Tyrol, Italy. B, position of the Puez locality on the Trento Plateau. C, east–west transect of the Lower Cretaceous plateau–basinal sequence of the South Alpine region. Bozen, Bolzano; Trient, Trento (see B); Col de Puez, Piz de Puez (2913 m). Black stars indicate positions of the Breggia and Puez localities. White dashed line marks the course of the *Halimedides* horizon (Hh).

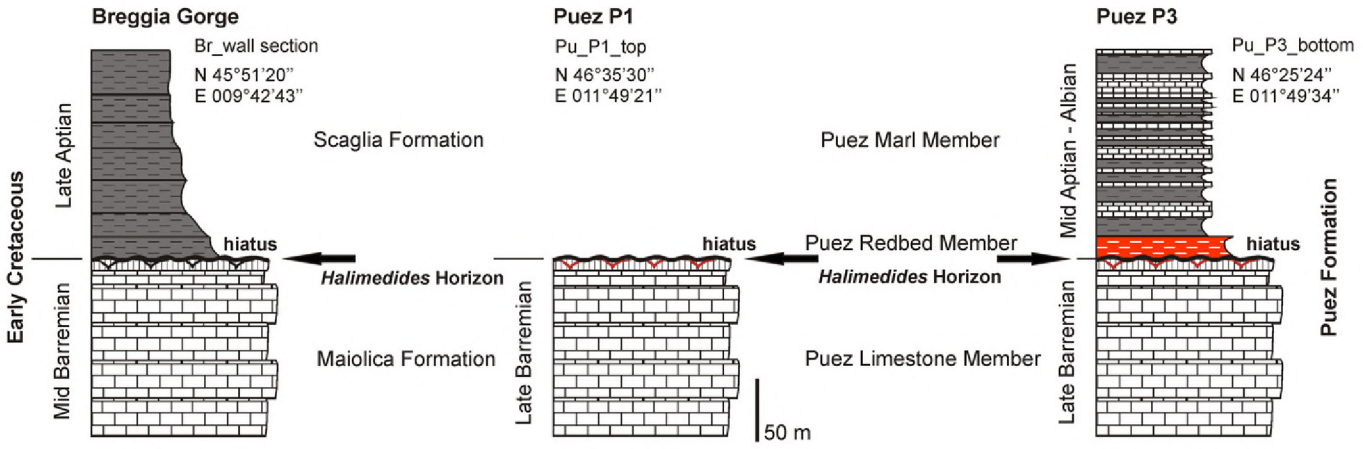


Fig. 2. The *Halimedides* horizon at different localities. From the left, the Breggia Gorge section and the Puez P1 and Puez P3 sections, showing the marker bed and the following hiatus.

on the basis of the presence of the planktonic foraminifera *Praehedbergella luterbacheri* and *Globigerinoides ferreolensis* between the lower Maiolica Formation and the overlying marlstones of the "Scaglia variegate". Therefore they assumed that sedimentation began after the gap with the early late Aptian of the *P. luterbacheri* and *G. ferreolensis* zones. This comparable lithological change accompanied by a sedimentological gap at Balerna was also reported by Channel et al. (1993), who indicated a hiatus spanning at least the late Barremian–early late Aptian.

3. Material

The samples studied were collected from the Puez locality (Fig. 1). Bed-by-bed collecting and a systematic-taxonomic study provide the basic data for statistical analysis of the investigated ammonites and trace fossils. Rock samples comprising *Halimedides*, *Spongeliomorpha* and *Zoophycos* are all from the top of bed P1/204 (Figs. 2–4). Additional material was collected from the same horizon all over the Puez area, correlated by the trace fossil assemblage and its red truncations. The material was collected during the last three years within the FWF project P20018-N10 and is stored in the South Tyrol Museum of Natural Sciences and the Natural History Museum in Vienna. Some samples are housed in the Institute of Geological Sciences of the Jagiellonian University (prefix INGUJP).

3.1. Ammonites

Ammonite data (Lukeneder, 2011, in press) show that the uppermost beds of the section P1, topped by bed P1/204, belong to the *G. sartousiana* Zone (for the most recent Lower Cretaceous ammonite zonation, see Reboulet et al., 2009). Numerous ammonite moulds from bed P1/204 of *Melchiorites cassidoides* and *Phylloptychyceras ladinum* (Fig. 5A–D) are penetrated by *Halimedides*. Traces are filled with red (Aptian) foraminiferal silt from the bed above. The *Halimedides* and *Spongeliomorpha* traces puncture all of the ammonite specimens from the upper to the lower side. Seventeen ammonites were found in bed P1/204 down to approximately 20 cm below the top of the bed.

3.2. Trace fossils

Halimedides annulata (Vialov, 1971) (Figs. 2–5) is a mostly straight, rarely slightly curved, simple horizontal to oblique, exceptionally sub-vertical unlined tubular burrow, 1.0–3.1 mm wide (average 2.3 mm), with a series of heart-shaped or subspherical chambers that are symmetrically distributed along the burrow. The chambers are 4.8–14 mm wide (average 7.6 mm) and about 3–9 mm long (average 4.7 mm), consequently oriented with its narrowing side in one direction, located at different intervals, ranging mostly from 7 to 11 mm. However, there are intervals without chambers that are up to at least 52 mm long. The tunnels are filled with reddish, structureless or rarely pelleted marlstone. Locally, the margins of some burrows display indistinct perpendicular annulations.

The taxonomy of this trace fossil was discussed by Uchman (1999). Gaillard and Olivero (2009) described *Halimedides* from different Lower Cretaceous horizons in pelagic deposits from the Alps and consider them as a deep-sea agrichnion in which chambers were used for food capture and storage, produced in stiff to firm substrates probably by a small crustacean.

Spongeliomorpha sp. (Figs. 3C–E, 4A, B, D) is represented by horizontal to sub-horizontal tubular, rarely branched, straight burrows, 5–15 mm in diameter, covered with scratch marks. The scratch marks are straight or slightly sinuous, 7–12 mm long, forming an anastomosing network that runs along the burrow, or occurring in sets that are oblique to the course of the burrow. The branches are Y-shaped and segments between branches are at least 180 mm long. In some segments of the burrows, scratch marks are not visible. In such cases a transition to *Thalassinoides* is possible. The burrow is filled with a red marlstone.

Spongeliomorpha is a crustacean burrow produced in a firmground. It has been synonymised with *Thalassinoides* and *Ophiomorpha* (e.g., Schlirf, 2000) but most authors continue to separate these ichnogenera. The anastomosing scratch mark pattern is similar to that in *Spongeliomorpha iberica* Saporta, 1877, which is interpreted as having been produced by shrimps scraping microbes from the burrow margin (de Gibert and Ekdale, 2010).

Zoophycos sp. (Fig. 4E, F) is a lobate planar, spreite structure oblique in respect to the bedding and encircled by a marginal tunnel that is 4 mm wide and filled with greenish, in some cases glauconitic, marlstone. The spreite laminae are 1–2 mm wide, arcuate, and arranged tangentially in respect to the marginal tunnel. The lobes are 40 to at least 50 mm wide, and some are at least 80 mm long. *Zoophycos* s.l. is generally considered a structure produced by, as yet undiscovered, deposit-feeders (e.g., Olivero and Gaillard, 1996, 2007), which are referred to as sipunculids (Wetzel and Werner, 1981), polychaete annelids, arthropods (Ekdale and Lewis, 1991), or echiuran worms (Kotake, 1992). Kotake (1991)

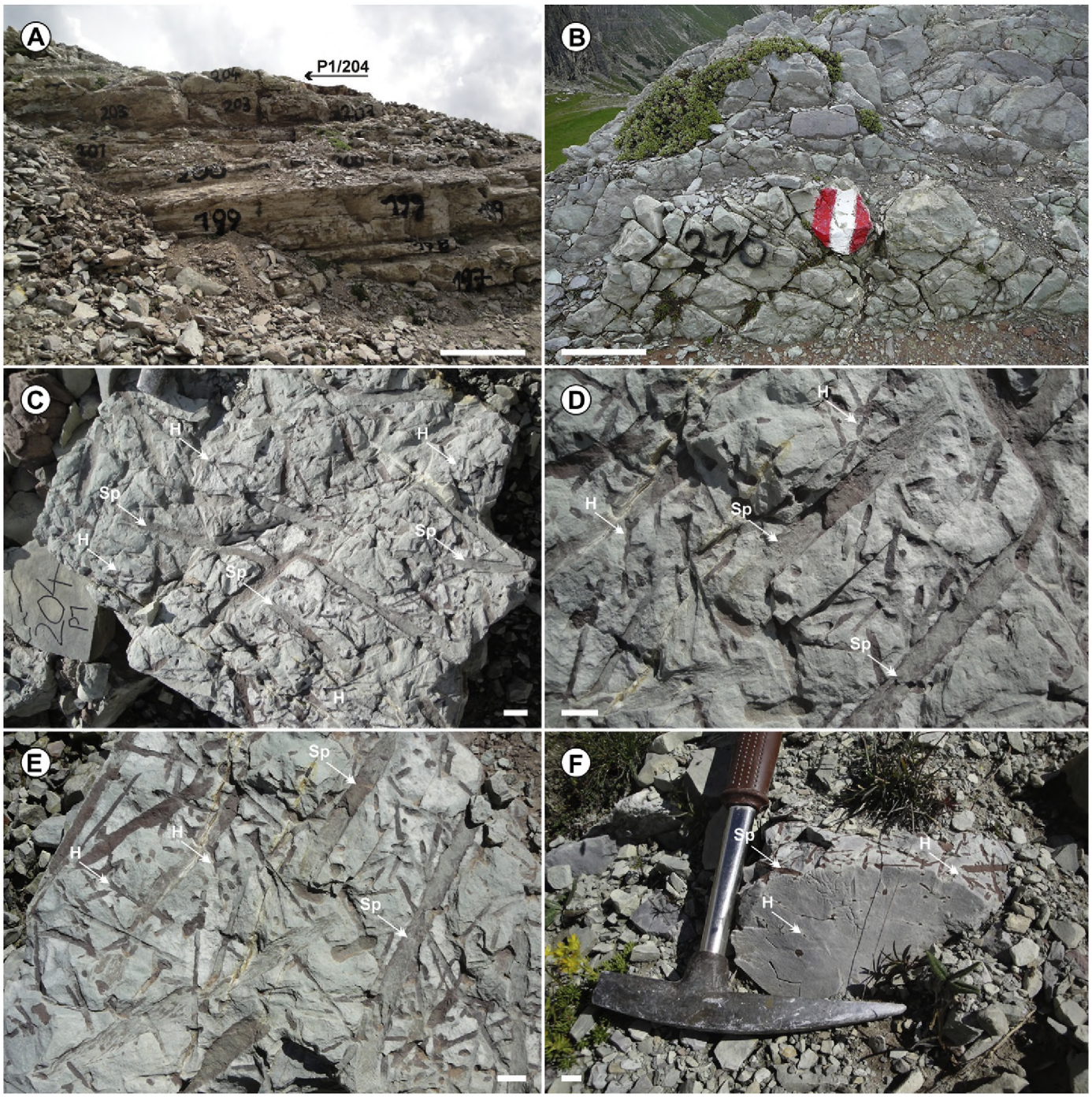


Fig. 3. A, location of the uppermost bed of log P1 with topmost bed P1/204. B, surface view of *Halimedides* horizon within log P3, bed P3/210 (= P1/204). C, sample of bedding plane showing *Halimedides* (H) and *Spongeliomorpha* (Sp), bed P1/204. D, magnification of C. E, surface of bed P1/204 showing *Halimedides* (H) and *Spongeliomorpha* (Sp). F, vertical section through cut rock sample showing sections of *Halimedides* and a penetrated depth of approximately 15 cm. Scale bars represent 50 cm in A, B, 1 cm in C–F.

showed that some Cenozoic *Zoophycos* are produced by surface ingestors of organic detritus. The precise ethological interpretation of this complex ichnogenus remains controversial. Bromley and Hanken (2003) suggested that the upper helical part of a large Pliocene *Zoophycos* from Rhodes, Greece, is a deposit-feeding structure, and lateral lobes developing from its lower part are sulphide wells for chemosymbiotic bacteria. *Zoophycos* indicates coherent sediments (Olivero, 1996; Olivero and Gaillard, 1996) and can occur in firmground substrates in distal settings (MacEachern and Burton, 2000).

4. Discussion

4.1. The Halimedides horizon: trace fossil community on the surface of bed P1/204

The density of burrows is high on the surface of the bed and *Halimedides* is clearly the dominant ichotaxon (Figs. 3, 4). *Halimedides* and *Spongeliomorpha* cross over each other and probably illustrate the same colonization phase. *Halimedides* is a rhabdoglyphid trace fossil commonly described from flysch deposits and

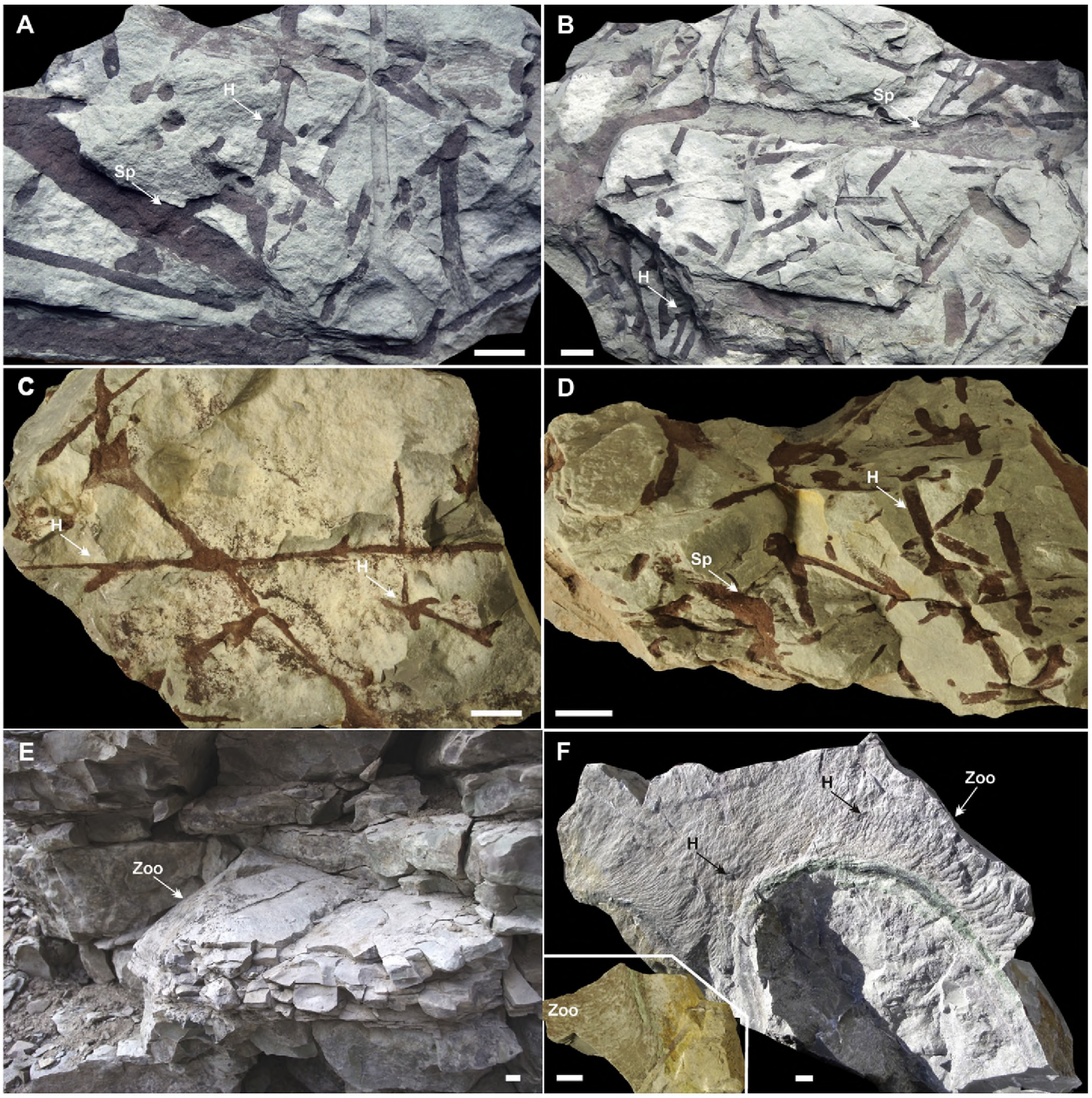


Fig. 4. A–D, rock samples from *Halimedides* horizon at Puez (P1/204) comprising *Halimedides* (H) and *Spongeliomorpha* (Sp). E, F, *Zoophycos* (Zoo, log P4) is 15 cm in diameter. Scale bars represent 1 cm.

preserved as a hypichnial convex relief. Under these conditions, *Halimedides* are predepositional burrows partially preserved after erosion of the sea floor. In the sections studied, burrows related to this ichnogenus are preserved as epichnia or endichnia near the top surface of a bed composed of pelagic mud. Most of the burrows penetrated up to 30 mm below the marker bed surface, but some to at least 70 mm. *Spongeliomorpha* exhibit scratch marks. The surface shows unroofed burrows. The absence of a roof can be explained by erosion but no smoothing by currents is observed. A collapse of roofs or burrowing on the boundaries of two lithologies is an alternative explanation. No fragments of collapsed roof have been encountered in the studied sections. Such fragments could have been winnowed away by currents but the problem of smoothing returns. Thus a burrowing between two lithologies, i.e., between firm limy mud and soft red marl is the most probable explanation.

4.2. Are trace fossils reliable indicators for sediment consistency?

Halimedides very probably occurred in different kinds of environments. However, the very strong similarities (taphonomy, position in the bed, morphology) occurring with specimens from different Cretaceous pelagic deposits from the Alps (Gaillard and

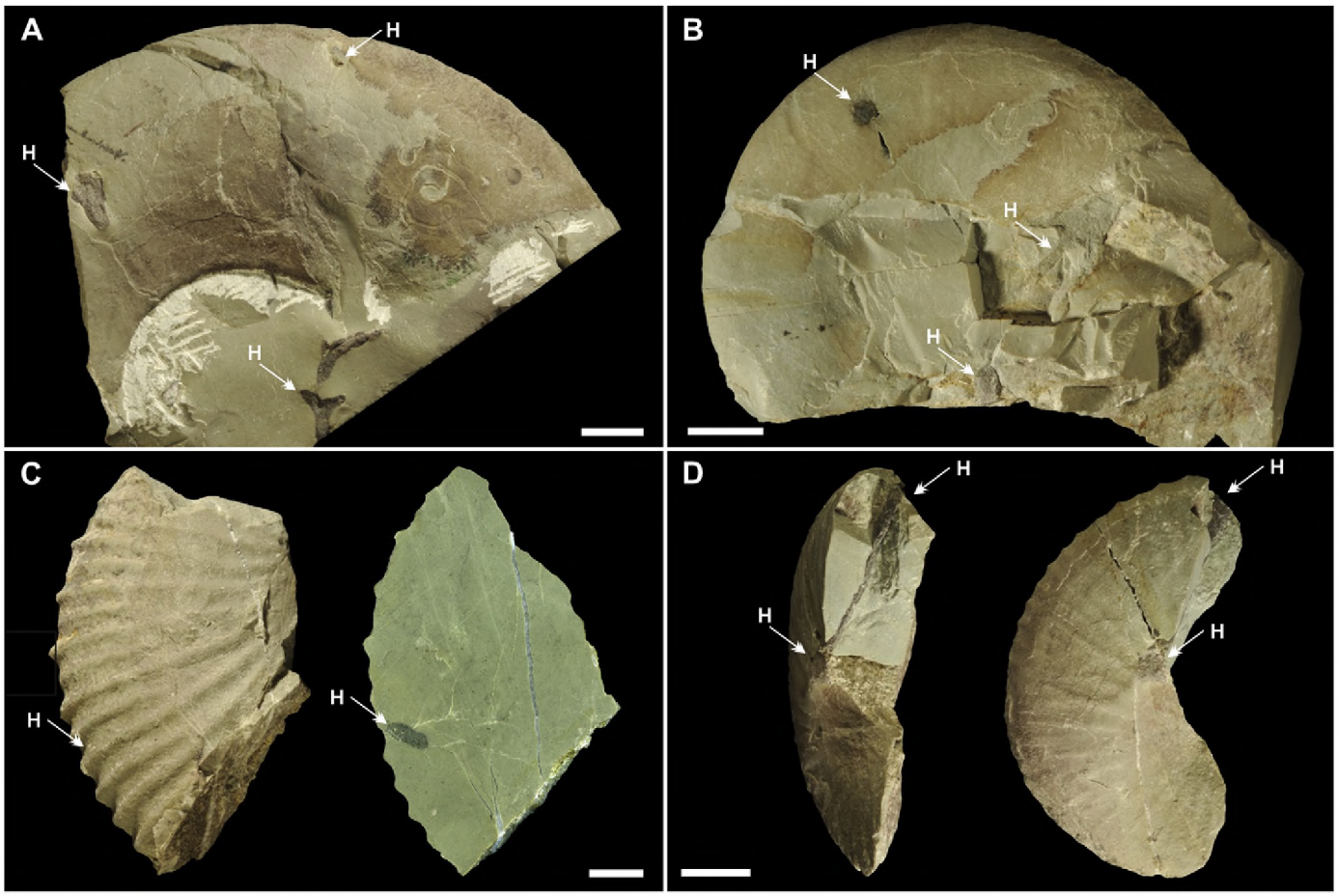


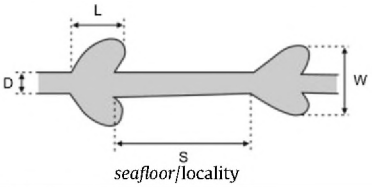
Fig. 5. A, mould of the ammonite *Melchiorites cassidoides* penetrated by *Halimedides* (H). B, *Melchiorites cassidoides* penetrated by *Halimedides*. C, *Phyllopachyceras ladinum* penetrated by *Halimedides*; left, lateral view; right, longitudinal, polished cross-section. D, *Phyllopachyceras ladinum* penetrated by *Halimedides*; left, dorsal view; right, lateral view. Scale bars represent 1 cm.

Olivero, 2009) allow interesting comparisons and possible conclusions to be made. First, it has been supposed that the co-occurrence of *Halimedides* and *Spongeliomorpha* probably indicates a deep-sea environment with pelagic deposits. The association of this ichnofauna with abundant ammonites, the absence of a diverse benthos and the very fine-grained sediment confirm this interpretation. Both *Halimedides* and *Spongeliomorpha* occurring on the upper surface of the bed 204 also clearly indicate a firmground, as observed in other Cretaceous bed surfaces (Gaillard and Olivero, 2009). *Spongeliomorpha* exhibits visible scratch marks attesting to this second statement but fine scratch marks, which may be observed on Cretaceous specimens of *Halimedides* from southeastern France, are not visible because of the filling of the burrow. Following these data, the upper surface of bed 204 clearly illustrates a deep-sea substrate exhibiting the *Glossifungites* ichnofacies (Seilacher, 1967; Pemberton et al., 2004; MacEachern et al., 2007), which is typical of firmground (e.g., Buatois and Mángano, 2011). By comparison with other known specimens, *Halimedides* from the Puez area are clearly "sparsely chambered" (Table 1). The association of *Halimedides* and *Spongeliomorpha* represents an omission suite of trace fossils according to Bromley (1996) where burrows were emplaced during a period of non-deposition. The hiatus occurring at the top of bed 204 is marked by an omission horizon that is directly overlain by the red Aptian Puez Redbed Member. This illustrates at least a long period of non-deposition corresponding to a part of the *G. sartousiana* Zone and the entire *Imerites giraudi* Zone. The succession of trace fossils in the suite is confirmed by the cross-cutting relationships. *Zoophycos* is cross-cut by *Halimedides* (Fig. 4F), and *Halimedides* seems to be more frequently cross-cut by *Spongeliomorpha* (Fig. 4A, B). These observations confirm that *Zoophycos* traces were formed in a softer but probably coherent substrate, possibly a stiffground (Olivero, 1996; Olivero and Gaillard, 1996; Gaillard and Olivero, 2009). Also, some *Zoophycos* are considered as a distal expression of the *Glossifungites* ichnofacies (MacEachern and Burton, 2000).

4.3. Age and duration of the late Barremian hiatus

At the Puez section the *Gerhardtia sartousiana* Zone ranges from bed P1/194 up to the end of log P1 with bed P1/204. The lower boundary is fixed by the first appearance of the zonal index ammonite *G. sartousiana* in bed P1/194 (Lukeneder, 2011). Based on the ammonite assemblage and further lithological and microfossil analysis, the upper two ammonite subzones, i.e., the *G. provincialis* and *Hemihoplites feraudianus* subzones, are probably missing, a hiatus occurring at the top of log P1 after bed P1/204. Bed P1/204 is directly overlain by Aptian sediments. *Halimedides* penetrated moulds of the ammonites *Melchiorites cassidoides* and *Phyllopaychyceras ladinum* (Fig. 5A–D). These can be found within bed P1/204 down to approximately 20 cm below the top, indicating the maximum depth of the *Halimedides* burrows. If the age model for ammonite zones from Ogg et al. (2008), in addition to sedimentation rates given by Lukeneder and Reháková (2004) for such hemipelagic sediments, are considered, it can be assumed that the

Table 1
Measurements of *Halimedides* observed in fine grained pelagic deposits from different localities. Chamber distance in *Halimedides* is meant to reflect consistency of sea-floor sediments.

	D tunnel diameter	L chamber length	W chamber width	S chamber spacing
firmground Puez area (this study)	1.0–3.1 mm $\mu = 2.3$ mm	3–9 mm $\mu = 4.7$ mm	4.8–14.0 mm $\mu = 7.6$ mm	8.0–12.5 mm $\mu > 10.7$ mm
firmground Breggia, Montblanc, Peipin	0.5–2.5 mm $\mu = 1.7$ mm	1–5 mm $\mu = 3.0$ mm	2.0–10.0 mm $\mu = 2.3$ mm	4.0–30.0 mm $\mu = 14.6$ mm
soft- to firmground La Charce, Bouviéres	0.5–2.5 mm $\mu = 1.7$ mm	1.0–6.0 mm $\mu = 3.4$ mm	5.0–10.0 mm $\mu = 7.8$ mm	3.5–18.0 mm $\mu > 6.9$ mm

duration of sedimentation of the uppermost 20 cm of bed P1/204 is approximately 200,000–300,000 years.

It was also noted by Wissler et al. (2002), based on a chemostratigraphic perspective, that the sedimentation, and consequentially the stratigraphy, was less continuous than generally assumed during the Barremian. At the stratotype of the Barremian (Angles), late Barremian sediments representing approximately 2 myr are missing (Wissler et al., 2002). According to Wissler et al. the gap is most probably located within the *I. giraudi* Zone.

The hiatus in the mid *G. sartosuiana* Zone is comparable to situations in south-east Spain (Company et al., 1994), where in the Capres section the *G. sartousiana* (including *H. feraudianus* Subzone) and the *Imerites giraudi* zones are condensed to within only 2 m. The condensed lower part was determined by the index species of *G. sartousiana* (*Heinzia sartousiana* in Company et al., 1994). Lithological differences observed in the Puez area are clearly a consequence of an altered palaeoceanography and, therefore, reflect sea-level fluctuations during the early Cretaceous, especially within the early late Barremian (*G. sartousiana* Zone; Lukeneder, in press). According to Weissert (pers. comm., 2011) the hiatuses around the Southern Alpine chain most probably reflect pulses in episodic bottom water current activity.

An interesting question is the possible relation of the characteristics of the observed ichnofauna and the duration of the period of non-deposition. In deep-sea pelagic deposits, when slight gaps are not proven, this duration can be estimated from substrate consistency. Bioturbation structures and ichnofauna are useful for recognizing soupgrounds, softgrounds, stiffgrounds, firmgrounds and hardgrounds according to the nomenclature introduced by Wetzel and Uchman (1998). In the Hauterivian section from La Charce (south-east France), which is characterized by regularly interbedded calcareous mudstone and marlstone, dense bioturbation structures (burrow mottles) indicate normal softgrounds whereas the rare occurrences of *Zoophycos* possibly indicate soft to stiffgrounds. Beds containing *Zoophycos* are followed by beds containing *Halimedides*, illustrating possible stiffgrounds related to short gaps not suspected by other methods (Gaillard and Olivero, 2009). The same succession with *Zoophycos* followed by *Halimedides* is observed in the Puez area. In the La Charce area, *Halimedides* is densely chambered, locally curved and clear gaps are not proven. In the Puez area, *Halimedides* it is quite different, i.e., sparsely chambered, straight, and associated with *Spongeliomorpha*, indicating a firmer substrate and a clear gap. This gap corresponds to a part of the *G. sartousiana* Zone and the entire *I. giraudi* Zone. A similar situation is known in a Lower Aptian unconformity visible in many areas of the Vocontian Basin (south-east France; Gaillard and Olivero, 2009). Within the localities in this basin, *Halimedides* is also sparsely chambered, straight, and associated with *Spongeliomorpha* and, in addition, with *Rhizocorallium*. The gap is very clear but, in some areas, without the disappearance of an entire ammonite zone (upper part of the *Deshayesites deshayesi* Zone following the lower part of the *Deshayesites weissi* Zone) and, in other areas, with the disappearance of several ammonite zones (Cotillon, 2010, fig. 3). Another example is the top surface of the Barremian Maiolica Formation (northern Italy and southern Switzerland). This corresponds to a long gap and is also characterized by sparsely chambered and straight *Halimedides* associated with *Spongeliomorpha* and *Rhizocorallium*. Here, the hiatus corresponds to an abrupt lithological break between limestones and marls and spans the late Barremian–early Aptian according to Arthur and Premoli-Silva (1982) and Channel et al. (1993). These authors assumed a restart of Aptian sedimentation for the overlying Scaglia marlstones after a gap within the early late Aptian *G. ferreolensis* Zone. In the Puez area, the absence of *Rhizocorallium* crossing *Halimedides* and *Spongeliomorpha* could indicate a shorter period of non-deposition.

The duration of ammonite zones is very variable (Ogg et al., 2008). Estimations for Jurassic and Cretaceous ammonite zones are based on biostratigraphic (Bulot and Thieuloy, 1993; Hantzpergue, 1993), chronostratigraphic (Ogg et al., 2008) or sedimentologic (Lukeneder and Reháková, 2004; Strasser, 2007) criteria. Lower Cretaceous ammonite zones (Reboulet et al., 2009) compared to data given by Ogg et al. (2008) lead to estimations varying from 400,000 to 1,400,000 years, but frequently are close to 1 myr. Following this average value, the duration of the period of non-deposition in the Puez area could be 1.5 myr. But other occurrences of firmgrounds with *Halimedides* in the Vocontian Basin indicate a shorter time, possibly one ammonite zone or less: 0.5–1 myr could be, very approximately, the duration of non-deposition necessary for the formation of a firmground in fine-grained pelagic deposits and colonization by straight, sparsely chambered *Halimedides*. If the combined data from ammonites (Lukeneder, in press) and planktonic foraminifera (Jan Sotak, pers comm. 2011) are considered, a hiatus extends from the *G. sartousiana* Zone up to the foraminiferal zones of *Praehedbergella luterbacheri* and *Globigerinelloides ferreolensis* of the earliest late Aptian. Ogg et al. (2008) assumed a duration of the approximately 5–6 myr for this interval.

5. Conclusions

The limestone sedimentation of the Puez Limestone Member ends abruptly with a significant hiatus within the early late Barremian *Gerhardtia sartousiana* Zone (*G. sartousiana* Subzone). This hiatus is marked at the top of bed 204 by an omission horizon,

directly overlain by the red Aptian Puez Redbed Member. The horizon contains the trace fossils *Halimedides*, *Spongeliomorpha* and *Zoophycos* (called here the *Halimedides* horizon). This situation is comparable to that at other localities in south-east Spain and Morrocco. The accompanying hiatus spans the late Barremian–middle/late Aptian. Taking into account combined data from ammonites and planktonic foraminifera the hiatus extends from the ammonite *G. sartousiana* Zone up to foraminiferal zones of *Praehedbergella luterbacheri* and *Globigerinelloides ferreolensis* of the earliest late Aptian, which amounts to approximately 5–6 myr.

Observed *Halimedides* characterize a firmground on ancient deep-sea floors. Colonization by the *Halimedides* tracemarker occurred after a relatively long period of non-deposition. In the Puez area, *Halimedides* observed on the upper surface of the bed 204 shows two interesting characteristics: firstly, the tunnel is very straight; secondly the burrow system is sparsely chambered (7 to at least 52 mm between two successive chambers). According to observations on coeval Cretaceous pelagic deposits in south-eastern France and Switzerland, this morphology indicates firmgrounds whereas densely chambered *Halimedides* are more likely to indicate less firm substrates. Such firmgrounds colonized with *Halimedides* could indicate a hiatus that lasted from 0.5 to 1 myr. Using available data from Cretaceous pelagic deposits from the Alps, the following suite of trace fossils expressing stiffening to hardening of the substrated in the marker bed can be proposed:

Bioturbation structures only	softground
Zoophycos	soft- to stiffground
Halimedides (densely chambered)	stiffground
Halimedides (sparsely chambered) + *Spongeliomorpha*	firmground
Halimedides (sparsely chambered) + *Spongeliomorpha* + *Rhizocorallium*	firmer firmground

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